

Charmless B Decays Involving Vector Mesons in Belle

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Using the data sample of 10.5fb^{-1} collected by the Belle detector, we searched for two-body charmless decays involving vector mesons. The clear signal signature of $B^\pm \rightarrow \phi K^\pm$ is seen and its branching fraction is measured to be $(1.39^{+0.32}_{-0.30} \pm 0.25) \times 10^{-5}$. The evidence for $B^\pm \rightarrow \rho^0 \pi^\pm$, $B^0 \rightarrow \rho^\mp \pi^\pm$ and $B^\pm \rightarrow \phi K^{*\pm}$ is reported and their branching fractions are determined. No significant signals are observed for $B^0 \rightarrow \phi K_S^0$, $\rightarrow \phi K^{*0}$, $\rightarrow \rho^\mp K^\pm$, $B^\pm \rightarrow \rho^0 K^\pm$, $\rightarrow \omega \pi^\pm$ and $\rightarrow \omega K^\pm$ only the 90% C.L. upper limits are given.

1 Introduction

The study of charmless B decays will play a significant role in checking the KM matrix description and in testing the validity of the Standard Model description of CP violation.

Decays involving $b \rightarrow ss\bar{s}$ transitions such as $B \rightarrow \phi K$ cannot occur via a tree process and are expected to be dominated by the penguin diagram, thus their measurement will give information on the strength of the penguin transition. They are also sensitive to physics beyond the Standard Model, since non-SM particles can contribute via additional loop diagrams.

The decay $B^0 \rightarrow \rho^\pm \pi^\mp$ is one of the preferred modes for determining the angle ϕ_2 of the unitarity triangle. The decays $B^\pm \rightarrow \rho^0 \pi^\pm$ and $B^\pm \rightarrow \omega \pi^\pm$ are interesting as they may exhibit large direct CP violation. The $B^\pm \rightarrow \rho^0 K^\pm$ channel may yield information about the angle ϕ_3 .

The first searches for $B \rightarrow \phi K$ decays modes were performed by the CLEO collaboration in data samples of gradually increasing integrated luminosities of 2.42, 3.11 and 5.5fb^{-1} but no evidence for these modes was found¹. The first evidence for the decay $B^\pm \rightarrow \phi K^\pm$ in a data sample of $5.5 \times 10^6 B\bar{B}$ pairs was reported by the Belle collaboration at the ICHEP2000 Conference in Osaka². The branching fraction was measured to be $\mathcal{B}(B^\pm \rightarrow \phi K^\pm) = (1.72^{+0.67}_{-0.54} \pm 0.18) \times 10^{-5}$. At the same conference, CLEO³ presented its first hints of the observation of this decay mode, quoting a branching fraction of $(0.64^{+0.25+0.05}_{-0.21-0.20}) \times 10^{-5}$. Recently CLEO reported⁴ measurements based on the data sample of $9.7 \times 10^6 B\bar{B}$ pairs: $\mathcal{B}(B^\pm \rightarrow \phi K^\pm) = (0.55^{+0.21}_{-0.18} \pm 0.06) \times 10^{-5}$ and $\mathcal{B}(B^0 \rightarrow \phi K^{*0}) = (1.15^{+0.45+0.18}_{-0.37-0.17}) \times 10^{-5}$ and 90% C.L. upper limits for the branching fractions of $B^{*\pm} \rightarrow \phi K^{*\pm}$ and $B^0 \rightarrow \phi K^0$ decays of 2.25×10^{-5} and 1.23×10^{-5} respectively⁴.

Charmless B decays into modes with $\rho(\pi/K)$ and $\omega(\pi/K)$ are hampered by large combinatorial backgrounds. These modes have only been seen recently, first

Table 1: The measured branching fractions by other experiments [10^{-5}].

Mode	BABAR(BF)	CLEO(BF)
$B^\pm \rightarrow \rho^0 \pi^\pm$	$2.4 \pm 0.8 \pm 0.3$	$1.04 \pm 0.33 \pm 0.21$
$B^\pm \rightarrow \rho^0 K^\pm$	$1.0 \pm 0.6 \pm 0.2$	$0.84 \pm 0.38 \pm 0.18$
$B^0 \rightarrow \rho^\mp \pi^\pm$	$4.9 \pm 1.3^{+0.6}_{-0.5}$	$2.76^{+0.84}_{-0.74} \pm 0.42$
$B^0 \rightarrow \rho^\mp K^\pm$	-	< 3.3 (90% C.L.)
$B^\pm \rightarrow \omega \pi^\pm$	-	1.13 ± 1.4
$B^\pm \rightarrow \omega K^\pm$	-	< 0.79 (90% C.L.)
$B^\pm \rightarrow \omega h^\pm$	$0.89 \pm 0.54 \pm 0.22$	-

by CLEO⁵ and then by BABAR⁶. The current branching fractions measured by CLEO and BABAR are given in Table 1.

2 The data sample and the Belle detector

The presented results are based on the data set collected by the Belle detector⁷ at KEKB⁸, the asymmetric B-factory at KEK. It consists of 10.5fb^{-1} taken at the $\Upsilon(4S)$ resonance and 0.6fb^{-1} taken below the $B\bar{B}$ production threshold used for continuum studies. The Belle detector is a general purpose magnetic spectrometer equipped with a 1.5 T superconducting solenoid magnet. Charged tracks are reconstructed in a 50 layer Central Drift Chamber (CDC) and in three concentric layers of double sided silicon strip detectors of the Silicon Vertex Detector (SVD). The SVD allows precise reconstruction of secondary decay vertices. The charged particle acceptance of the spectrometer covers the laboratory polar angles $17^\circ < \theta < 150^\circ$ which corresponds to $\sim 90\%$ of the full CMS solid angle. Photons and electrons are

identified using the CsI(Tl) Electromagnetic Calorimeter (ECL) located inside the magnet coil. Muons and K_L^0 's are detected using resistive plate chambers embedded in the iron magnetic flux return (KLM). Charged particles are identified using specific ionization losses in the CDC and identification information from the Aerogel Cherenkov Counters (ACC) and Time of Flight Counters (TOF). By these three methods, K/π separation is achieved over the momentum range from about 0.2 to 3.5 GeV. The high momentum kaon identification efficiency is determined to be $\sim 80\%$ (at a purity of greater than 85%).

3 Event selection

In the search for the above channels we take full advantage of asymmetric e^+e^- collisions resulting in boosted $B\bar{B}$ pairs, good vertexing and particle identification capabilities of the Belle detector.

The details of analysis are optimized for each channel separately. For lack of space, only the main steps in the analysis can be described.

We search for $\phi \rightarrow K^+K^-$ decays by selecting pairs of oppositely charged tracks consistent with kaon hypothesis (which accepts kaons with $> 90\%$ efficiency) and $|M_{KK} - M_\phi| < 10\text{MeV}$. Events with a candidate ϕ are accepted if the ϕ momentum in the CMS exceeds 2.0 GeV.

Candidate $\rho^0 \rightarrow \pi^+\pi^-$ decays are required to have dipion invariant masses which satisfy $|M_{\pi\pi} - M_{\rho^0}| < 220\text{MeV}$, while the ρ^\pm candidates are required to satisfy $|M_{\pi^\pm\pi^0} - M_{\rho^\pm}| < 200\text{MeV}$.

The ω is reconstructed in decay mode $\omega \rightarrow \pi^+\pi^-\pi^0$. We require both π^0 's daughter photons carrying energy greater than 50 MeV. A variable, defined as the cross product of the $\pi^+\pi^-$ momentum vs π^0 in the ω rest frame (called ω -amplitude) is used to suppress the combinatorial background. The $\pi^+\pi^-\pi^0$ mass is required to be within a $\pm 30\text{MeV}$ window from the nominal ω mass.

The charged tracks used in the ω/ρ reconstruction are required to be inconsistent with lepton or kaon. The required level of particle identification (PID) for accompanying kaons K^\pm , $K^{*\pm}$, K^{*0} , is optimized using the measured kaon efficiency and pion misidentification curves. At the chosen cut value the kaon identification efficiency exceeded 80%. For $K_S^0 \rightarrow \pi^+\pi^-$ decays we use oppositely charged track pairs where the displacement of the $\pi^+\pi^-$ vertex from the interaction region in the transverse ($r-\phi$) plane is more than 1 mm. The ϕ coordinate of the $\pi^+\pi^-$ vertex point and the ϕ direction of the $\pi^+\pi^-$ vertex point agree within 0.2 radians and $|m_{\pi\pi} - m_{K^0}| < 15\text{MeV}$. The K^* candidates are reconstructed in four modes: $K^{*0} \rightarrow K^\pm\pi^\mp$, $K^{*0} \rightarrow K_S^0\pi^0$, $K^{*\pm} \rightarrow K^\pm\pi^0$ and $K^{*\pm} \rightarrow K_S^0\pi^\pm$. The invariant mass

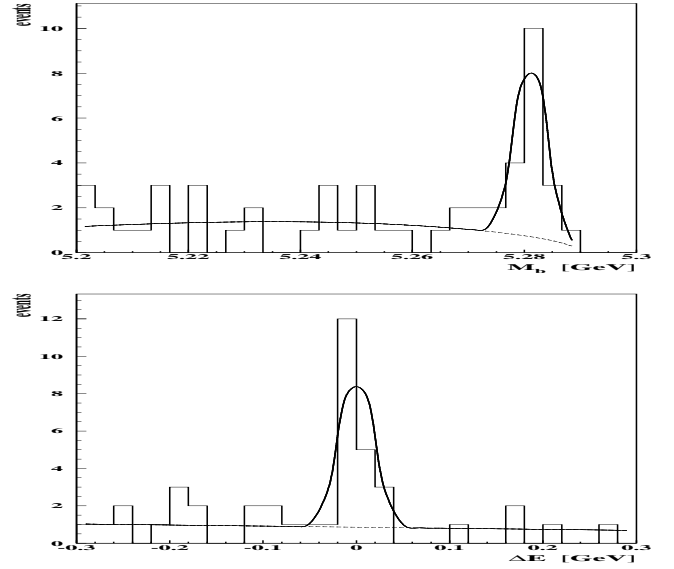


Figure 1: The M_b (top) and ΔE (bottom) distribution for selected $B^\pm \rightarrow \phi K^\pm$ candidates. The curves are projections of the unbinned ML fit.

is fitted with the beam spot constraint (described below) and the signal window is defined within $\pm 50\text{MeV}$ of the nominal resonance mass.

4 B meson reconstruction

The selected vector meson and the pseudoscalar (or vector) are combined to form the B-meson decay candidate. The vertex fit of the B candidate is performed with a beam spot constraint ($\sigma_x \approx 100\mu\text{m}$, $\sigma_y \approx 5\mu\text{m}$ and $\sigma_z \approx 3\text{mm}$) enlarged by a halo corresponding to the width expected for the B meson lifetime ($\approx 20\mu\text{m}$ in the transverse plane). A run dependent interaction point position and beam spot size are used.

The candidate B decay is identified by a beam constrained mass $M_b = \sqrt{(\sqrt{s}/2)^2 - P_B^{*2}}$ and the calculated energy difference $\Delta E = E_B^* - \sqrt{s}/2$, where E_B^* and P_B^{*2} are the energy and 3-momentum of the B candidate in the $\Upsilon(4S)$ rest frame. The width of the B signal region in M_b and ΔE depends on the expected resolutions for each decay mode.

The continuum background has been suppressed using observables: the angle between the B candidate momentum vector and the thrust vector of the remaining tracks of the event ($|\cos(\theta_{thr-B})|$), and the B candidate production angle in the CMS ($|\cos(\theta_B^*)|$). For $B \rightarrow PV$ decay channels an additional variable is used: $|\cos(\theta_H)|$, where the helicity angle θ_H is the angle between the direction of the K/π and the momentum vector of $\phi/\rho/\omega$,

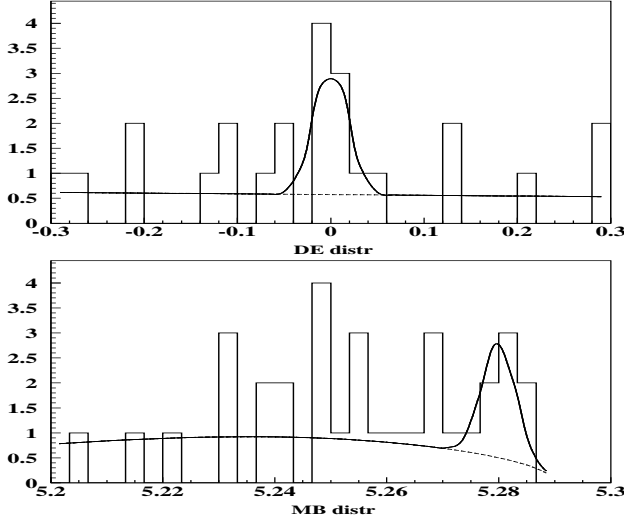


Figure 2: The M_b (top) and ΔE (bottom) distributions for $B^\pm \rightarrow \phi K^\pm$ candidates. The curves are projections of the unbinned ML fit.

Table 2: The fit results for $B \rightarrow \phi K$ modes.

Mode	fitted signal yield	significance
$B^\pm \rightarrow \phi K^\pm$	$17.8^{+4.8}_{-4.2}$	7.5σ
$B^0 \rightarrow \phi K^{*0}$	$6.5^{+3.5}_{-2.7}$	3.6σ
$B^\pm \rightarrow \phi K^{*\pm}$	$1.3^{+1.8}_{-1.1}$	1.4σ
$B^0 \rightarrow \phi K_S^0$	$0.9^{+1.7}_{-0.9}$	1.2σ

in the vector meson rest frame ^a.

4.1 $B \rightarrow \phi K$

The continuum background suppression is performed by sequential cuts; $|\cos(\theta_{thr-B})| < 0.8$ and $|\cos(\theta_B^*)| < 0.8$. For $B^\pm \rightarrow \phi K^\pm$ and $B^0 \rightarrow \phi K_S^0$ channels an additional cut is used: $|\cos(\theta_H)| > 0.5$. The signal yield in each studied decay channel is extracted from the unbinned maximum-likelihood fit. The fits are made simultaneously in M_b - ΔE plane. The signal in M_b and ΔE is adequately represented by a single Gaussian. The background distribution for M_b is represented by the ARGUS function^b. The background in ΔE is parametrized by a

^aIn a Pseudoscalar(P) \rightarrow Pseudoscalar - Vector(V) decay the vector meson is polarized, decaying to two pseudoscalars $V \rightarrow PP$ according to a $\cos^2(\theta_H)$; the combinatorial background is flat in $\cos(\theta_H)$.

^b $B(x) = N\sqrt{1-x^2}\exp(P(1-x^2))$; where $x = \frac{M_b}{E_{beam}^*}$, P is the shape variable fitted to background sample and N is the overall normalization factor fitted to the distribution in the signal region.

Table 3: The fit results for $B^0 \rightarrow \rho^\pm \pi^\mp$ modes.

data sample	fitted signal yield	significance
$\cos(\theta_H) > 0$	$10.9^{+5.5}_{-4.8}$	2.6σ
$\cos(\theta_H) < 0$	$10.1^{+5.5}_{-4.7}$	2.4σ

linear function.

The accepted candidates for $B^\pm \rightarrow \phi K^\pm$ are shown in Fig. 1. The fit gives $17.8^{+4.8}_{-4.2}$ signal events. The statistical significance of the signal yield is 7.5σ ^c. The efficiency for this decay mode is 11.8%, which includes detector acceptance and the intermediate BF.

The results of the fit for $B^\pm \rightarrow \phi K^{*\pm}$ decays candidates is shown in Fig. 2. The fitted number of signal events is $6.5^{+3.5}_{-2.7}$ with significance of 3.6σ . The efficiency for this decay mode is 4.0%.

The results of the fits for other $B \rightarrow \phi K$ modes are summarized in Table 2.

4.2 $B \rightarrow \rho \pi^\pm$

In these channels another discrimination observables are used: an angle between the ρ and the beam axis in the B rest frame. In addition the extended Fox-Wolfram⁹ moments are used (Super Fox-Wolfram moments). The moments are combined to maximize the separation between signal and background distributions.

The variables are combined into Likelihood ratio \mathcal{L} for better background rejection. The probabilities of being the signal (p^{sig}) and background (p^{bck}) are calculated for each of the variables and the likelihood ratio is formed $\mathcal{L} = \frac{p^{sig}}{p^{sig}+p^{bck}}$. A cut is made at $\mathcal{L} > 0.9$.

The possible cross talk from $B^\pm \rightarrow D^0 \pi^\pm$; $D^0 \rightarrow K^\pm \pi^\mp$ which can imitate $B^\pm \rightarrow \rho^0 \pi^\pm$; $\rho \rightarrow \pi^+ \pi^-$ is removed by checking the D^0 decay hypothesis.

The fit for $B^\pm \rightarrow \rho^0 \pi^\pm$ in the ΔE projection only (with M_b cut) gives the signal yield of $13.73^{+6.53}_{-5.85}$ at significance of 2.9σ and efficiency of 13.4%. The result is confirmed in the fit to the M_b distribution, which gives a significance of 3.4σ .

For the $B^0 \rightarrow \rho^\pm \pi^\mp$ mode, the $\cos(\theta_H) > 0$ and $\cos(\theta_H) < 0$ regions are fitted separately. The yield is determined from a simultaneous fit to the M_b and ΔE distributions

The fit results are shown in the Table 3. The significance of the signal yield predicted by the fit to both subsamples combined is 3.5σ .

^cThe statistical significance of the signal yield is defined as $\sqrt{-2\log(L_0/L_{max})}$, where L_0 corresponds to the value at zero signal yield hypothesis.

Table 4: The fit results for $B \rightarrow \rho^\pm K^\mp$ modes.

data sample	fitted signal yield	significance
$\cos(\theta_H) > 0$	$5.0^{+3.8}_{-3.3}$	1.9σ
$\cos(\theta_H) < 0$	$4.6^{+4.1}_{-3.3}$	1.5σ

Table 5: The fit results for $B \rightarrow \omega h$ modes.

Mode	fitted signal yield	significance
$B^\pm \rightarrow \omega\pi^\pm$	$2.8^{+3.6}_{-2.7}$	1.0σ
$B^\pm \rightarrow \omega K^\pm$	$3.4^{+3.0}_{-2.2}$	1.8σ
$B^\pm \rightarrow \omega h^\pm$	6.4 ± 8.9	1.8σ

4.3 $B \rightarrow \rho K^\pm$

For the $B^\pm \rightarrow \rho^0 K^\pm$ mode the fit is made simultaneously in the M_b and ΔE planes. The fit results are given in the Table 4. The significance of the signal is only 2.2σ .

For the $B^0 \rightarrow \rho^\pm K^\mp$ mode the fit in the ΔE projection is performed (with M_b cut). The fit gives signal yield of $8.29^{+5.07}_{-4.43}$ with significance of 2.0σ (in the case of the fit to M_b only the significance is 1.8σ) and efficiency of 12.8%.

4.4 $B^\pm \rightarrow \omega h^\pm$

As in the $B \rightarrow \rho h$ search, a cut on a likelihood ratio which includes the ω -*amplitude* is used to suppress the continuum background. The cut is set at $\mathcal{L} > 0.95$. The unbinned likelihood fit to M_b and ΔE is used to extract the signal yields. No signal is observed.

The $\omega\pi$ and ωK yields are obtained from the simultaneous fit. For the ωh mode, the particle identification information is not applied in the fast charged tracks selection. The results are summarized in Table 5.

5 Conclusions

Using the data sample of 10.5fb^{-1} collected by the Belle detector, a search was performed for two-body charmless decays including vector meson. A clear signal signature of $B^\pm \rightarrow \phi K^\pm$ is seen with 7.5σ significance. The branching fraction for this mode is measured to be $(1.39^{+0.32}_{-0.30} \pm 0.25) \times 10^{-5}$. Evidence $B^\pm \rightarrow \rho^0 \pi^\pm$, $B^0 \rightarrow \rho^\mp \pi^\pm$ and $B^\pm \rightarrow \phi K^{*\pm}$ is reported. For $B^0 \rightarrow \phi K_S^0$, $B^0 \rightarrow \phi K^{*0}$, $B^\pm \rightarrow \rho^0 K^\pm$, $B^0 \rightarrow \rho^\mp K^\pm$, $B^\pm \rightarrow \omega\pi^\pm$ and $B^\pm \rightarrow \omega K^\pm$ no significant signals are observed and the 90% C.L. limits are given.

Table 6: The summary of the obtained branching fractions and upper limits $[\times 10^{-5}]$.

Mode	BF	UL 90% C.L.
$B^+ \rightarrow \phi K^+$	$1.39^{+0.37+0.14}_{-0.33-0.24}$	-
$B^0 \rightarrow \phi K^0$	-	< 1.6
$B^0 \rightarrow \phi K^{*0}$	$1.5^{+0.8}_{-0.6} \pm 0.3$	< 3.0
$B^+ \rightarrow \phi K^{*+}$	-	< 3.6
$B^+ \rightarrow \rho^0 \pi^+$	$1.12^{+0.53}_{-0.48} \pm 0.19$	< 2.88
$B^+ \rightarrow \rho^0 K^+$	-	< 1.35
$B^0 \rightarrow \rho^+ \pi^-$	$2.02^{+0.83}_{-0.66} \pm 0.33$	< 3.57
$B^0 \rightarrow \rho^+ K^-$	-	< 2.36
$B^+ \rightarrow \omega h^+$	-	< 1.41
$B^+ \rightarrow \omega\pi^+$	-	< 0.94
$B^+ \rightarrow \omega K^+$	-	< 1.05

Acknowledgments

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